Generating Electricity: Discount Store Physics

JOURNEYS IN FILM
educating for global understanding

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About *Journeys in Film*

Founded in 2003, ***Journeys in Film*** operates on the belief that teaching with film has the power to prepare students to live and work more successfully in the 21st century as informed and globally competent citizens. Its core mission is to advance global understanding among youth through the combination of age-appropriate films from around the world, interdisciplinary classroom materials coordinated with the films, and teachers' professional-development offerings. This comprehensive curriculum model promotes widespread use of film as a window to the world to help students to mitigate existing attitudes of cultural bias, cultivate empathy, develop a richer understanding of global issues, and prepare for effective participation in an increasingly interdependent world. Our standards-based lesson plans support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

Selected films act as springboards for lesson plans in subjects ranging from math, science, language arts, and social studies to other topics that have become critical for students, including environmental sustainability, poverty and hunger, global health, diversity, and immigration. Prominent educators on our team consult with filmmakers and cultural specialists in the development of curriculum guides, each one dedicated to an in-depth exploration of the culture and issues depicted in a specific film. The guides merge effectively into teachers' existing lesson plans and mandated curricular requirements, providing teachers with an innovative way to fulfill their school districts' standards-based goals.

Why use this program?

To be prepared to participate in tomorrow's global arena, students need to gain an understanding of the world beyond their own borders. ***Journeys in Film*** offers innovative and engaging tools to explore other cultures and social issues, beyond the often negative images seen in print, television, and film.

For today's media-centric youth, film is an appropriate and effective teaching tool. ***Journeys in Film*** has carefully selected quality films that tell the stories of young people living in locations that may otherwise never be experienced by your students. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven,* play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home,* watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider,* tour an African school with a Nobel Prize–winning teenager in *He Named Me Malala,* or experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble.*

In addition to our ongoing development of teaching guides for culturally sensitive foreign films, ***Journeys in Film*** brings outstanding documentary films to the classroom. We have identified exceptional narrative and documentary films that teach about a broad range of social issues in real-life settings such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. ***Journeys in Film*** guides help teachers integrate these films into their classrooms, examining complex issues, encouraging students to be active rather than passive viewers, and maximizing the power of film to enhance critical thinking skills and to meet the Common Core Standards.

Journeys in Film is a 501(c)(3) nonprofit organization.

A Letter from Chiwetel Ejiofor

I hope you enjoyed watching the film *The Boy Who Harnessed the Wind.*

William's story embodies the creativity of young people and acts as a powerful reminder of the achievements we can make when we are not afraid of failure. He encountered many obstacles, but his determination to get an education and unstoppable drive to do what he believed in will act, I hope, as an inspiration to you in this course.

This film tells the true story of a family in Malawi and the difficulties they faced; external factors like the weather, environment, politics, religion, and education have a profound effect on the daily life of many Malawians. I hope this film and the course spark a much wider discussion and action to engage with some of the issues that the film touches on.

William's story continues to inspire the next generation of innovators in Africa and around the world. I hope that watching *The Boy Who Harnessed the Wind* and the curriculum help to inspire you to never give up on your dreams.

Yours sincerely,

Generating Electricity: Discount Store Physics

Enduring Understandings

- Electric and magnetic forces underlie many everyday interactions.
- Many technological devices convert energy from one form to another, more useful form.
- Technological devices are designed and built by humans, and so they can be taken apart and analyzed by humans.
- With ingenuity, technological devices can be reused for purposes other than originally intended.

Essential Questions

- What do electric and magnetic interactions reveal about the atomic scale properties of materials?
- How do circuits convert energy from one form to another?
- How does an electric motor use the relationship between electric and magnetic forces to convert energy supplied by an electric current into mechanical energy?

Notes to the Teacher

If you want to make it, all you have to do is try.

—William Kamkwamba

The activities in this lessons are designed to get students thinking about electric and magnetic interactions, simple circuits, and common consumer devices that use electromagnetism in one way or another. The themes are exploration, troubleshooting, and qualitative analysis. In some places, the instructions are left deliberately vague because there are multiple good ways (and plenty of bad ways) to do each activity. Encourage your students to explore different ways of making their devices work. Remind them that not all of William Kamkwamba's experiments succeeded. The ones that did work usually involved several iterations and missteps along the way.

The lesson is by no means a complete qualitative introduction to electrostatics or to circuits. Several important experiments from the typical introductory sequence are missing. For example, none of the activities explore induced charge, and although students work with DC motors, they don't explore electromagnetic induction directly, e.g., with bolts wound with wire.

Of course, you can also use more specialized, higher-quality equipment in the activities you do with your students. To make more advanced circuits with more components such as capacitors, resistors, transistors, and so on, it's cheaper, easier, and more effective to buy in bulk from an online supplier--but there are advantages to the "discount store" theme:

- It is in keeping with the spirit of the film, emphasizing both thrift and creative use of materials.
- Students work with "real" devices, not devices custom made for education. These devices cease to be "magic" black boxes whose inner workings can only be understood by a select few.
- It encourages breaking the mold of functional fixedness in the minds of students. Objects can be repurposed for something other than they were intended.
- Because of the low cost, you can make more equipment available to students—and if something breaks, it can be affordably replaced.
- Students can bring their labs home with them, or even obtain the materials on their own. One advantage to a homework lab is that it allows for more exploration. Of course, since you won't supervise those labs, choose activities carefully, and reinforce good safety practices.

The lesson is suitable for any of the following groups:

- A middle school physical science class
- A ninth-grade conceptual physics course
- An intro to circuits activity for a high school engineering course or robotics club
- A summer project for students entering an Honors or AP Physics course
- Home-schooled students at middle or high school levels

Note that the amount of time required for each activity can vary greatly from group to group. It is also possible to conduct one or more of the experiments as a teacher demonstration.

Activity 1

The first part of the lesson introduces students to the concept of energy and delineates a number of different types of energy. Students experiment with using balloons to test the differences between conductors and insulators. This is of course not the only way to introduce electrostatics. Any selection of materials from the triboelectric series can work. Another fun, quick demonstration is to show that a stream of water from a faucet is attracted by a charged object. A good resource for ideas about activities in electrostatics is *the Physics Classroom* (https://www.physicsclassroom.com/class/estatics).

You may find it useful to project the multiple-choice problems here and elsewhere in front of the class, to better generate discussions. Of course, don't give answers before the students have had a chance to test their predictions. It should go without saying, but please try all the activities yourself before you have your students do them. You are also encouraged to dismantle some of the devices in the Extension Activities—quite a lot of fun—and if you enjoy it, your students will pick up on that excitement.

Activity 2

The second activity (**Handouts 3** and **4**) is similar to the "sticky tape" activity near the beginning of the E&M sequence from the American Modeling Teacher's Association (AMTA) at www.modelinginstruction.org; this site has additional activities to provide a more thorough investigation. Note that electrical tape seems to work better for this activity than Scotch™ tape. The tape is easier to manipulate, and it holds its charge longer.

This lesson deliberately avoids the terms "positive" and "negative" until the very end. It is preferable not to use those words until you discuss the results. Emphasize that the assigning of a negative charge to the electron is merely a convention. Many students operate under the assumption that there is some fundamental requirement that protons have positive charge and electrons negative charge.

For many students, their only experience with electrostatics is the attraction due to polarization. They are often surprised to find out that electrostatic forces can be repulsive. Even though most students have heard there are two different types of charge, many of them have not made the connection between this idea and the behavior of macroscopic objects.

Note that in some buildings, the metal structure may change the local magnetic field to point in a different direction from the Earth's intrinsic magnetic field. However, even then, the magnetized screwdrivers should still align with one another. (Of course, test it beforehand!) The main point still stands: to illustrate the existence of a magnetic field.

Hanging the screwdrivers with long thread in Step 9 of **Handout 4** is necessary because the torque on the screwdrivers due to the Earth's magnetic field is quite small. If the screwdrivers were just on a table, there would be too much friction to see anything happen.

While it may seem to be an elementary activity, I strongly recommend it. Arnold Arons describes the conceptual challenges concerning magnets faced by most students [Arons, Section 6.6; see Additional Resources below]. This specific activity is also detailed in Arons. Some of the main points:

- Most students have played with common refrigerator magnets, but many have never encountered magnet-magnet repulsion.
- While many students know what a compass does, they don't think of the tiny compass needle as a magnet, even if they've been told so.
- Even if students have heard of magnetic poles before, they often think of them as somehow the same as electric positive and negative charges.

Another good demonstration is to carefully cut one of the magnetized screwdrivers crosswise into two pieces. You can then show that each piece is itself a magnet with two poles. Magnetic poles cannot be separated – all magnets are bipolar.

The screwdrivers are not sensitive enough to easily show the vertical component of the magnetic field – the Earth's magnetic field points diagonally down in much of the Northern Hemisphere. However, they at least partially show the three-dimensional nature of the field, given that all the magnetized screwdrivers point in roughly the same direction, regardless of vertical or horizontal location in the room.

More broadly, this activity shows students that, with care, you can discover things that are not readily apparent. The force exerted by the Earth's magnetic field is not strong compared to everyday forces, and yet it's everywhere around us, all the time.

A good follow-up is any set of activities that explores qualitatively how polarization, charge transfer, and induced charge work in a dielectric on an atomic scale. For example, the AMTA physics modeling materials guide students to sketch each of these phenomena in several different scenarios.

Activity 3

The "interlude" on **Handout 5** is simply preparation for the next activities. The wire in the wire set can be challenging to work with. It is not very flexible, and it also tangles easily. Wire is typically reasonable in cost, so it is recommended that higher-quality copper wire is used if possible. If you use wire with a clear lacquer instead of a plastic coating, have students sand the lacquer off the ends with fine sandpaper rather than stripping the wire with the long nose pliers.

Activity 4

A common preconception among introductory physics students is that the charge carriers are somehow "used up" in a circuit, whereas in reality they travel continuously around the circuit. Having the student struggle with **Handout 6** to figure out how to make a circuit work goes some distance towards dispelling this myth.

Another helpful activity to do in conjunction with this one is the class battery/bulb/wire challenge. Give each student or group one length of wire, one battery, and one incandescent light bulb. Challenge them to light the bulb with only these materials.

It's also worth telling the students that the drift speed of the electrons in a typical DC circuit is actually quite slow, on the order of tens or hundreds of *micrometers* per second. Many students are under the mistaken impression that electrons in a wire travel at or near the speed of light, whereas it is actually the electromagnetic wave that travels this quickly. (See Chris Baird's web page "What Is the Speed of Electricity?" at https://wtamu.edu/~cbaird/sq/2014/02/19/what-is-the-speed-of-electricity/ for an excellent analogy to help your students understand the difference.)

Activity 5

In this activity, students test what happens when different sizes of batteries are used. The water analogy at the end of **Handout 7** is a useful visualization for physics students at an introductory level, even though it becomes problematic later on when considering various phenomena such as electromagnetic induction in greater, more quantitative detail. One of the most difficult hurdles for student comprehension of circuits is visualization, so even slightly flawed analogies are worth using.

Activity 6

You may also do the usual introductory physics investigation, analogous to the one in **Handout 8**, with small incandescent light bulbs. The goal is to solidify in students' minds how these qualitative relationships arise because of the way the electric potential energy of the charge carriers changes throughout the circuit. Depending on the course, qualitative investigation of Ohmic and non-Ohmic resistive components can come later.

As mentioned in the references, Chabay and Sherwood have an excellent discussion of how the microscopic distribution of charge changes the potential gradient in a circuit during the first moments it is connected to an emf-providing device.

Activity 7

It is strongly recommend that you have your students make simple electromagnets with a large nail or bolt and some copper wire. The discount store wire is not quite up to the task, but you can substitute a couple of feet of thin, insulated copper wire. There are numerous resources online describing how to build a simple electromagnet; for example, *Build an Electromagnet* at http://sciencenetlinks.com/student-teacher-sheets/build-electromagnet/ or *Hands-on Activity: Creating an Electromagnet* at https://www.teachengineering.org/activities/view/cub_mag_lesson2_activity1.

Next Generation Science Standards addressed by this lesson

MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

[Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.]

[Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

[Clarification Statement: Examples of this phenomenon could include the interactions of magnets, electrically-charged strips of tape, and electrically-charged pith balls. Examples of investigations could include first-hand experiences or simulations.]

[Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.]

MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

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[Assessment Boundary: Assessment is limited to electric and magnetic fields, and limited to qualitative evidence for the existence of fields.]

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

[Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.]

[Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

[Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.]

[Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

[Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.]

[Assessment Boundary: Assessment is limited to systems containing two objects.]

Common Core Standards addressed by this lesson

Analyze proportional relationships and use them to solve real-world and mathematical problems.

7.RP.2. Recognize and represent proportional relationships between quantities.

- **a.** Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin.
- **b.** Identify the constant of proportionality (unit rate) in tables, graphs, equations, diagrams, and verbal descriptions of proportional relationships.
- **c.** Represent proportional relationships by equations. For example, if total cost t is proportional to the number n of items purchased at a constant price p, the relationship between the total cost and the number of items can be expressed as $t = pn$.
- **d.** Explain what a point (x, y) on the graph of a proportional relationship means in terms of the situation, with special attention to the points (0, 0) and (1, r) where r is the unit rate.

Use random sampling to draw inferences about a population.

7.SP.1. Understand that statistics can be used to gain information about a population by examining a sample of the population; generalizations about a population from a sample are valid only if the sample is representative of that population. Understand that random sampling tends to produce representative samples and support valid inferences.

7.SP.2. Use data from a random sample to draw inferences about a population with an unknown characteristic of interest. Generate multiple samples (or simulated samples) of the same size to gauge the variation in estimates or predictions. For example, estimate the mean word length in a book by randomly sampling words from the book; predict the winner of a school election based on randomly sampled survey data. Gauge how far off the estimate or prediction might be.

Reason quantitatively and use units to solve problems.

N-Q.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

N-Q.2. Define appropriate quantities for the purpose of descriptive modeling.

N-Q.3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

Duration

Three to four class periods, or two extended lab periods.

Assessment

Student responses to multiple choice problems.

Discussions of predictions and results.

Construction of functioning devices.

Materials

Individual materials (one for each student)

Copies of **Handouts 1–9**

Safety goggles

Dish pan for storing lab materials

Roll of PVC electrical tape

All-purpose scissors (may also be shared among 3 to 4 students)

Precision screwdriver set with magnetized tips and flat bases (may also be shared among 3 to 4 students)

Eyeglass repair kit (with non-magnetized screwdrivers) (may also be shared among 3 to 4 students)

Craft storage box for storing small screws and odds and ends

Wire set

Paper towel holder

Long nose pliers (may also be shared among 3 to 4 students)

Personal mini fan

Package of six AA batteries

Package of binder clips

9V battery

Organizer case for storing batteries

Shared Materials (for up to 24 students)

1 bag of 25 latex balloons

1 box aluminum foil

1 package dental floss or sewing thread

8 packages of three D cell batteries

1 package six AAA batteries

1 package C cell batteries

(**All materials could be found very affordably at online or in-person discount variety stores. Note that certain items are seasonal.**)

Procedure

1. Start by asking the class to name things that they associate with the word *energy*, listing them on the board in your classroom. (It doesn't matter how outlandish a comment is—the idea is to brainstorm.) Use this as a springboard into a discussion centered around the question, "What is Energy?" Through gradual prompting, help students arrive at some of the important points about the general properties of energy. Also encourage them to classify the ways that energy can be stored. They don't have to get all the terminology right; the point is to get them thinking more precisely about concepts that they probably haven't given much thought to until now.

2. Distribute **Handout 1: What Is Energy?** and assign as reading for homework or allow time in class for reading. The discussion in Step 1 should solidify and organize their understanding of how energy is defined and classified. Wrap up the discussion by writing the following definition on the board for students to copy or by locating the definition of energy in your textbook for them to review:

   Energy is the ability to do work. It can be stored in various forms and transferred from place to place. Given a reference frame, an object moving or rotating with respect to that frame stores kinetic energy, and two or more interacting objects can store potential energy as they get closer together or farther apart. If we consider large collections of atoms and molecules, kinetic energy and potential energy are usually called thermal energy and chemical energy.

3. Review the safety precautions on **Handout 1** with students before beginning the activities. Ask students to explain why each item is important.

4. Distribute **Handout 2: About Clingy Things**, along with the materials listed on the handout. Assign students to work in small groups. Each time students reach a multiple-choice question here and elsewhere in the lesson, project it on screen. Solicit responses from the students and ask them to defend their choices. Have students clear their work areas.

5. Distribute **Handout 3: PVC Sandwich, Hold the Mayo**, along with the materials listed on the handout. Continue to have the students work in small groups. The results of this activity, when done correctly, will probably be surprising to many students. Make sure to dedicate time to a discussion of the implications. Finishing up to this point is near the maximum that can be accomplished in Day 1, for a 50- to 60-minute class period. Make sure students clean their work areas before moving on.

6. Distribute **Handout 4: You're Standing in a Field Somewhere**, along with the materials listed on the handout. Continue to have the students work in small groups. Once the students hang their screwdrivers, they may proceed to the activities in **Handout 5**.

7. Distribute **Handout 5: Interlude: Cutting and Stripping**, along with the materials listed on the handout. Continue to have the students work in small groups. Since this activity requires little discussion, students can start it as soon as they finish **Handout 4**. You can return to a class discussion of **Handout 4** once the screwdrivers have had a chance to settle. Another option is to assign the cutting and stripping of wires for homework. Make sure students clean their work areas before moving on.

8. Distribute **Handout 6: It's Hot, Please Close the Fan**, along with the materials listed on the handout. Continue to have the students work in small groups. Although there are no specific questions for the students to answer, it's worth taking the time to walk around and have different students trace the path that current follows in their circuits. This activity will probably take the class through the end of Day 2. Make sure students clean their work areas before moving on.

9. Distribute **Handout 7: Pumps and Tanks**, along with the materials listed on the handout. Continue to have the students work in small groups. It's worthwhile to spend a good bit of time discussing the questions in this activity and their implications. This is the first activity that truly requires visualization of what is going on in an electric circuit, which most students have a great deal of difficulty with at first. Make sure students clean their work areas before moving on.

10. Distribute **Handout 8: Series and Parallel**, along with the materials listed on the handout. Continue to have the students work in small groups. There are a lot of conceptual questions in this handout, so leave enough time for a discussion of each point. This activity will probably take the class to the end of Day 3, or even into Day 4. Make sure students clean their work areas before moving on.

11. Distribute **Handout 9: E&M—Epilogue**, along with the materials listed on the handout. This activity is intentionally open-ended, without many instructions provided. It is a chance for students to put their problem-solving skills and ingenuity to the test. This activity will probably take the class into Day 4 or to the end of Day 4. Make sure students clean their work areas when they are finished.

Extension Activities

Many small gadgets found at discount stores are worth taking apart and investigating. The cost constraints placed on the design of these objects lead to some interesting circuits. They must be simple and easy for workers to assemble. They must use an absolute minimum of material, and at the lowest possible cost. It's hard not to admire the engineers who designed them. Perhaps as an unintended side effect, the workings end up relatively straightforward for a motivated student to understand.

LED String Lights

There are ten LEDs in this set. By trying a single 1.5-volt battery instead of two, students can see that LEDs require a certain minimum voltage in order to function. Even if they cut out a single LED and apply 1.5 V, the LED will not work, but with 3.0 V it will light. Students can also see that LEDs, like all diodes, are directional—they only function with a forward bias.

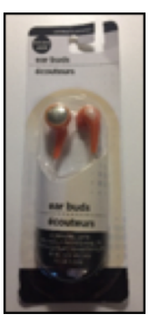
Solar Stake Light

This is a fascinating device. It is a very simple circuit, with only a solar panel, an inductor, a rechargeable battery, and a transistor-like device acting as an oscillator. The article *Hacking an LED solar garden light* at https://ez.analog.com/university-program/b/blogs/posts/hacking-an-led-solar-garden-light provides an excellent description of its workings and has several ideas for other projects with the device.

Mini Powered Speaker

This speaker contains an LED, a small audio amplifier (Texas Instruments, model number LM4871), and of course a speaker. The speaker is magnetic (instead of piezoelectric), and provides another illustration of a current producing a magnetic field. Since there is no rotation, the speaker's operation may be even easier for students to grasp than the motor's.

Ear Buds



Most students have used earbuds before. That alone makes it worth taking a pair apart, to investigate the workings, especially in comparison to the larger speaker. With care, students can find the small magnet inside each earbud, and note that the circuit is extremely simple: changes in the current and voltage cause the magnet to vibrate at different frequencies and amplitudes. With a powerful enough amplifier, you can also demonstrate to students that a speaker is a microphone in reverse.

Window and Door Alarm

This device contains a magnet, a reed switch, a transformer, and a piezo speaker. The speaker is not magnetic, of course, because it would interact with the sensitive reed switch, which is closed by the magnet.

Quite a lot of simple and curious devices that are worth dismantling can be found at various online or in-person discount stores. Two examples in the United States are Dollar General Corporation™ and Five Below Inc™. For more ideas, there are countless videos and blogs available online documenting hacking of inexpensive consumer electronic devices. Happy tinkering, and may not all your engineering be reverse!

Additional Resources

American Modeling Teacher's Association (AMTA) at https://modelinginstruction.org/
The modeling method of teaching physics has been used in the classroom by thousands of teachers for more than twenty years. By certain metrics, such as the Force Concept Inventory, it is one of the most effective ways of teaching physics. Many activities in this lesson are inspired partly or entirely by the modeling physics community. The author uses modeling methods in the physics classroom.

Arons, Arnold B. *Teaching Introductory Physics*. Wiley, 1997. Arnold Arons was one of the pioneers of physics education research. This encyclopedic work is an extraordinarily helpful reference for putting yourself in the mind of a beginning physics student. It details what preconceptions people have

before taking physics and describes strategies for effectively training students to think like physicists.

Atwater, Mary. *Using Energy*. Macmillan McGraw-Hill, 1995.
This book, William Kamkwamba's original inspiration, is unfortunately out of print. As of this writing, a few used copies are available online at ridiculous markups.

Chabay, Ruth W. and Sherwood, Bruce A. *Matter and Interactions*. 3rd ed., Wiley, 2011.
This text is an excellent resource for instructors and students. The book clearly describes and diagrams the multiple connections between the microscopic and macroscopic behavior of circuits, both conceptually and quantitatively.

Epstein, Lewis Carroll. *Thinking Physics Is Gedanken Physics*. Third ed., Insight Press, 2009.
This is an excellent source of puzzles in introductory physics. While the questions are phrased at a very introductory level, some of them are quite challenging, even for professional physicists! The multiple-choice problems in this lesson are inspired by Epstein's.

Hewitt, Paul G. *Conceptual Physics*. Eleventh ed., Pearson, 2010.
The classic conceptual physics text. It is a rare gem—a textbook you can just sit down and read, for pleasure.

Kamkwamba, William and Mealer, Bryan. *The Boy Who Harnessed the Wind*. HarperCollins, 2009.
Many more of Mr. Kamkwamba's experiments are detailed in the book than in the movie. He goes into great and entertaining detail about both his successes and his failures. If you decide to try to replicate some of his projects, be careful, as some of them are quite dangerous!

Mims, Forrest M. *Getting Started in Electronics*. Master Publishing, Inc., 2000.
This book describes exactly 100 circuit projects for the budding scientist or engineer to try. Half the book is devoted to explaining the operation of resistors, capacitors, LEDs, transistors, relays, speakers, and so on in an easy-to-understand way. The figures alone are more than worth the price of the book.

Handout 1 ▸ P. 1

What Is Energy?

Africans bend what little they have to their will every day. Using creativity, they overcome Africa's challenges. Where the world sees trash, Africa recycles. Where the world sees junk, Africa sees rebirth.

—Erik Hersman, quoted by William Kamkwamba in his book, *The Boy Who Harnessed the Wind*

I noticed a book I'd never seen, pushed into the shelf and slightly concealed. What is this? *I thought. Pulling it out, I saw it was an American textbook called* Using Energy*, and this book has since changed my life.*

—William Kamkwamba

In this lesson, you will dismantle, investigate, and build devices that convert energy from one form to another. Most, if not all, technology works by converting energy from a widely available form to a directly useful form. In the film *The Boy Who Harnessed the Wind*, William Kamkwamba repurposes many parts from old devices and from scrap heaps. In that spirit, you will be using low-cost parts whenever possible. Many of these are available from so-called "discount stores."

William Kamkwamba was originally inspired by the book *Using Energy* by Mary Atwater. What is energy? Perhaps it's best to start exploring energy by understanding what you can and can't do with it.

- You can't create new energy.
- You can't destroy existing energy.
- You ***can*** transfer energy from place to place.
- You ***can*** store energy.
- You ***can*** change the storage form of energy.

There are different names that we use for the various storage forms of energy. Objects can store energy by moving or by spinning. This is called **kinetic energy**. You have more kinetic energy when you're running than when you're standing still. A figure skater has more kinetic energy when spinning than when standing still.

Two or more massive objects can store energy when they're pulled apart. This is called **gravitational potential energy**. You and the Earth have more gravitational potential energy when you're on top of a tall mountain than when you're at sea level. That's because when you climbed the mountain, you increased the distance between you and most of the rest of the atoms on the Earth.

Springs can store energy when they're compressed or stretched out. This is called **spring potential energy**. Toy car launchers, NERF™ guns, pogo sticks, trampolines, and other such objects work by storing spring potential energy and then converting it to other forms of energy.

The total of kinetic energy, gravitational potential energy, and spring energy is sometimes called **mechanical energy**.

What Is Energy?

Electrically charged objects (which we'll explore soon) can store energy when they're pulled apart or pushed together. This is called **electric potential energy**.

Two or more atoms can store energy when they're pulled apart, pushed together, or formed into different shapes. Although this is partly about electric potential energy on a small scale, this is usually called **chemical energy** when dealing with large collections of molecules, as we do in everyday life. You change chemical energy into other forms of energy all the time. For example, this happens when you burn something, when you eat food, and when you use a battery in any sort of device.

Atoms and molecules can store energy by shaking, spinning, bumping into each other, and moving from place to place. Although this is partly about kinetic energy on a small scale, this is usually called **thermal energy** when dealing with large collections of molecules, as we do in everyday life.. The temperature of an object tells you something about the average thermal energy of its atoms and molecules.

"Energy is all around you every day," it said. "Sometimes energy needs to be converted to another form before it is useful to us. How can we convert forms of energy? Read on and you'll see."

I read on.

—William Kamkwamba, quoting the book *Using Energy*

A Note About Safety

You must wear safety goggles for all experiments. There will occasionally be bits of metal and plastic flying about. Getting a small, sharp piece of metal in your eye will likely result in permanent damage. Act like a professional: wear eye protection!

Safety Precautions

I climbed to the top of the tower and, as usual, kicked off my flip-flops so I could get a better grip. But the wind was violent and angry, pushing the tower from side to side so much that I thought it would tip. I wrapped my legs through the rungs and held on for life. But in trying to keep my balance, I didn't notice the bicycle frame swinging forward along with the tower. The next gust of wind sent the blades straight into my hand and knocked me off balance. I slipped and nearly fell, grabbing hold of the rungs and cursing. Looking at my hand, I saw the blades had shaved the meat off three of my knuckles, which were now dripping blood that scattered with the wind.

—William Kamkwamba

What Is Energy?

- Always wear your goggles.
- Keep your work area clean and free from debris.
- Take special care with flammable material, such as cardboard packaging.
- Keep batteries in an insulated container, such as a craft storage box or **organizer case**. Always put batteries away when not using them, ***even if only for a few minutes***. Do not keep any other materials with the batteries, especially flammable materials or metallic materials.
- Store spare bits of wire separately from batteries.
- Don't build anything that would produce a large current. Don't put more small batteries in a series larger than about 12 volts worth.
- Don't swallow batteries. Obviously. And yet in the United States alone, several people every year—mostly small children—receive permanent or fatal injuries after swallowing batteries. If a battery gets lodged in the wrong place, it can cause serious burns to internal organs. See the Poison Control website for button battery ingestion statistics at https://www.poison.org/battery/stats and the article "Batteries Cause Devastating Injuries" at https://www.poison.org/articles/button-batteries.
- Batteries are properly placed in a circuit with the positive end of one battery touching the negative end of the next battery. At one point, you will be asked to place two batteries the wrong way; only do this with two batteries as directed. Do not place a row of batteries in a circuit this way and then place one in the opposite direction. You can burst the battery casing and leak battery acid.

OK, after all those warnings, this may sound strange: don't be afraid to mess something up! It's part of the learning process. **If you're taking appropriate safety precautions**, the worst-case scenario is that you lose a few dollars' worth of equipment.

Disposal of batteries

In many places, small batteries are considered non-hazardous and may be disposed of in the trash. One exception to this is the state of California, which considers all batteries to be hazardous waste. Follow your local guidelines for battery disposal. See the Environmental Protection Agency guidelines at https://www.epa.gov/recycle/used-household-batteries for additional information.

Handout 2 ▸ P. 1

About Clingy Things

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 balloon from the bag of 25 latex balloons
1 piece of scrap paper
1 small square of aluminum foil

Procedure

Tear up a piece of scrap paper into small bits, roughly 5 mm across. Scatter the bits on a desk or table. Blow up a balloon and tie off the end. Rub the balloon on your hair. Hold the balloon over the bits of paper, with the side you rubbed closest to the bits of paper. Describe what happens.

You may have heard that objects are made of extremely small particles called **atoms**. Sometimes the atoms are clumped into small groups called **molecules**. The atoms themselves are made of other, smaller particles: **protons**, **neutrons**, and **electrons**.

In some materials, a few of the electrons can easily move from place to place, if they stay within the object. These materials are called **conductors**. (In a solid object, the protons and neutrons are always stuck, no matter what.) Most conductors are metals, but there are exceptions.

In some materials the electrons can't easily escape the atoms or molecules. These materials are called **insulators**.

Electrons are **electrically charged**, which means they can be pushed or pulled by electric forces. Paper is an insulator, so its electrons can't move all around the paper, but they can be jostled from place to place ***within*** the molecules they're stuck in.

By the way, electrons are ***not*** energy, but they can store energy, just like any other object. A moving electron stores kinetic energy. Two or more electrons can store electric potential energy. So can an electron and a proton, or a proton and another proton, or bigger groups of electrons and protons.

Handout 2 ▸ P. 2 About Clingy Things

When you rub the balloon on your hair, you're rubbing electrons off one surface and onto the other. This messes up the charge balance on you and the balloon. The balloon can now exert an electric force, so when you hold the balloon up to the bits of paper, it jostles the electrons around just a smidge. That smidge is enough that the electric force on the protons and electrons no longer quite cancels out.

Everything gets jostled around in just the right way so that the bits of paper are attracted to the balloon. The electrons rearrange themselves to try to "correct" the unbalanced charge on the balloon.

Imagine you do the same thing, but with bits of aluminum foil, instead of bits of paper. What will happen?

- ☐ **A.** The bits of aluminum foil will be attracted to the balloon.
- ☐ **B.** The bits of aluminum foil will be repelled by the balloon.
- ☐ **C.** Nothing will happen. The bits of aluminum foil will just sit there.

Now test your prediction. Briefly record what you tried and what happened.

Aluminum is a conductor. Some of the electrons can move around freely in the aluminum. Compared to the electrons in the bits of paper, the electrons in aluminum have even more freedom to move and attempt to "correct" the balloon's unbalanced charge. However, aluminum is more than twice as dense as paper, so it's harder to accelerate each bit.

Notice that you never rubbed the paper or the aluminum. The charges just jostled around a bit, but none of them left the material. This process is called **polarization**.

On the other hand, with the balloon and hair, you added or removed some charged particles from each object. When you charge objects by friction, each object gets an unbalanced amount of charge.

You saw that when you hold a charged object (balloon) up to a polarized object (paper, foil), the objects are attracted. Advertisers for dryer sheets call this "static cling."

Handout 3 ▸ P. 1

PVC Sandwich, Hold the Mayo

Materials

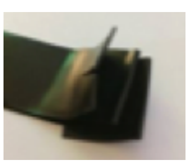
1 pair of safety goggles for each person
1 Dishpan for storing lab materials
1 roll of PVC electrical tape
1 pair of all-purpose scissors
1 balloon from the bag of 25 latex balloons

Procedure

1. Using a pair of scissors, cut off six pieces of PVC electrical tape, each about 15 cm long. (You don't need a ruler—just estimate.) Hang them off the edge of a desk or table to keep them organized. Fold over about 1 cm on one end of each strip, to form a non-sticky "handle."

2. 
Place the longest two strips side by side on the surface of a desk or table, sticky side down. Run your finger over them a few times to make sure they're flat. We'll call these the **base strips**. They will stay in the same place for the entire activity.

3. Layer two more strips on top of the base strips, sticky side down. Run your finger over them to flatten them. We'll call these the **down strips**.

4. 
Layer the last two strips on top of the down strips, and again run your finger over them to smooth them out. We'll call these the up strips. Find some way to mark the up strip in each three-layer sandwich. For example, poke a small hole in each up strip with a pen, or use a pair of scissors to make a small cut in their handles.

5. From one of the sandwiches, grab the up strip and down strip together by their handles. Peel them up together, trying to keep the base strip on the table. If the base strip comes up, just tear the base strip off and put it back on the table.

6. Pinch the up strip and down strip together with your fingers, and rub along their surfaces, as if you're squeezing the water out of a small sponge. Using both hands, tear the up strip and down strip away from each other.

7. Flip one strip over, so the sticky sides don't face each other. Bring the strips close together, but try not to let them touch. Briefly record what happened in your notebook. Then hang these up strip and down strips along the edge of your desk or table.

Handout 3 ▸ P. 2

PVC Sandwich, Hold the Mayo

8. Repeat steps 5–7 with the other three-layer sandwich. Briefly record what happened in your notebook. Hang this second set of up strip and down strips along the edge of your desk or table.

9. Now take the two up strips and bring them close together, without letting them touch. Then do the same thing with the two down strips. Briefly record what happened.

10. Hold a pen or pencil near each type of tape. Briefly record what happened.

11. Charge a balloon as you did in the previous activity. Bring it near each type of tape, without letting it touch. Briefly record what happened.

Handout 4 ▸ P. 1

You're Standing in a Field Somewhere…

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 precision screwdriver set
1 eyeglass repair kit
2 to 3 small screws, steel paperclips, or other small iron objects
1 craft storage box for storing small screws and odds and ends
1 balloon from the bag of 25 latex balloons
1 roll of PVC electrical tape
1 pair of all-purpose scissors
1 container of dental floss (or 1 roll of sewing thread)
1 unused classroom or large closet with a low ceiling and little air flow

Procedure

Work through the following procedure step-by-step. Don't jump ahead or read ahead until you have completed the step you are working on.

1. The screwdrivers in the precision screwdriver set are magnetized. This is to make it easier to pick up and manipulate small screws. Verify that the screwdrivers are magnetic by holding them up to a screw, a paperclip, or some other small metal object.
2. The screwdrivers from the eyeglass repair kit are not magnetized. How can you verify this? Try it, and briefly record what happened in your notebook.
3. Take out two magnetized screwdrivers. Balance one of them on your finger, parallel to the floor. Using your other hand, hold the tip of the other screwdriver next to the pointy end of the screwdriver on your fingertip. Briefly record what happened.
4. Now hold the opposite end of the metal part of one screwdriver up to the pointy end of the screwdriver that is balanced on your fingertip. (The "opposite end" of the metal part of the screwdriver is actually somewhere in the middle of the screwdriver.) Briefly record what happened.
5. Now hold the tip of one screwdriver up to the opposite end of the metal shaft of the screwdriver that is balanced on your fingertip. (This is roughly in the center of the screwdriver.) Briefly record what happened.

Handout 4 ▸ P. 2

You're Standing in a Field Somewhere…

All magnets have two sides to them, called **poles**. Somewhat arbitrarily, the poles of a magnet are called the north pole and the south pole. But they just as easily could have been called the red pole and the blue pole, or the truth side and the beauty side.

Opposite poles attract each other, and similar poles repel each other. Even if you cut a magnet into two pieces, each piece still has two poles. No one has ever seen just a north pole or just a south pole by itself, even though many scientists have looked very hard.

William Kamkwamba explains it better:

I also knew about the magnet's opposing sides. If you had two magnets, one side would always fight the other, refusing to stick together. However, flip one of the magnets over and it will snap to its fellow magnet.

6. Now choose your answer to this question: Are magnetic poles and electric charge the same thing?

☐ **A.** Yes, they're the same thing.

☐ **B.** No, they're completely unrelated.

☐ **C.** No, but they're related somehow.

Briefly explain your choice.

7. Blow up a balloon, then rub it against your hair or someone else's. Balance a magnetized screwdriver on your fingertip. Bring the charged side of the balloon close to the point end of the screwdriver. Then try the same thing, but with the balloon close to the other end of the screwdriver. Briefly record what happened.

8. Using PVC electrical tape, make a three-layer sandwich as you did in the previous activity. Pull off the "up" and "down" strips, then pull them apart. Remember to mark them somehow so you can tell them apart. Hang them from the edge of your table or desk. Bring one of the magnetized screwdrivers close to the "up" tape, then close to the "down" tape. Briefly record what happened.

You're Standing in a Field Somewhere…

Are these observations enough to rule out one of the options in the last multiple-choice question? Explain.

9. Cut off a long (more than one meter) piece of dental floss or sewing thread. The longer, the better, but it can't be longer than the ceiling-to-floor distance. Find the point at which the screwdriver balances on your fingertip. Tie one end of the thread at this point, so that the screwdriver hangs roughly horizontally, parallel to the floor. Secure it with a small piece of PVC electrical tape.

Tape the other end of the thread to the ceiling. (If you need to stand on a ladder, chair, or table, have a classmate spot you.) Use PVC electrical tape, painter's tape, or other tape that comes off easily. Do not use clear "sticky tape," often referred to in the United States by the brand name Scotch Tape™.

Repeat with at least two other magnetized screwdrivers. Do the same with several non-magnetized screwdrivers from the eyeglass repair kit. Keep them spaced at least a meter apart. If you are working with other classmates, you may want to hang far more screwdrivers. The result will be more dramatic.

10. Now make your prediction: What will happen after you leave the room for a while?

- ☐ **A.** All the screwdrivers will line up with each other and about point the same way.
- ☐ **B.** None of the screwdrivers will line up. They'll all still point in random directions.
- ☐ **C.** Only the magnetic screwdrivers will line up with each other. They will point about the same way.
- ☐ **D.** Only the magnetic screwdrivers will line up with each other. Each one will point the opposite way from its nearest neighbor.

Explain your reasons for this prediction.

Then leave the room where the screwdrivers are hanging for at least ten minutes. Briefly record what happened when you return.

Handout 4 ▸ P. 4

You're Standing in a Field Somewhere…

Here is William Kamkwamba's explanation:

The north pole of the magnet will always attract the south pole, while two similar poles push away from each other. Because of its liquid iron core, the earth itself is a kind of large bar magnet, with magnetic north and south poles. Magnets, just like the earth, have natural magnetic fields that radiate between the poles. These lines are invisible, of course, but if you were to see them, they'd appear like the wings of a butterfly. One end of the bar magnet will always be pulled toward the magnetic north pole of the earth. This is how a compass works—inside there's a small bar magnet that finds north and keeps you from getting lost.

What do you think of Mr. Kamkwamba's assertion? Did you just make a room full of compasses?

11. For certain types of forces, you can figure out a size and direction for that force in ***every*** location. The physics term for this is a **field**.

- The Earth exerts a gravitational force on every object. Is there such a thing as a gravitational field? If so, where is it? Which way does it point? If not, why?

- Your arm can exert a force on other objects. Is there such a thing as an arm field? If so, where is it? Which way does it point? If not, why?

- Is the activity with the magnetic screwdrivers enough to tell which way the Earth's magnetic field points? Explain.

Handout 5

Interlude: Cutting and Stripping Wire

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 wire set
1 paper towel holder
1 long nose pliers

Procedure

We are going to need a lot of wire for the rest of the activities, so let's take a moment and figure out how to prep some wire.

Open the wire set package and remove the wire loops. It's best to leave the wire loops coiled and tied off until you need them.

Once you start using a wire, it's easy for it to get tangled. To avoid this, keep the loop on a paper towel holder, laboratory ring stand, or similar object.

The wire has a plastic insulating coating. This keeps the electrons in the wire from flowing where you don't want them to. However, the ends of the wire must be bare metal, so you need to "strip" away the plastic insulation. There are several ways to do this. We will use the long nose pliers to both cut and strip the wires.

The pliers have a small section with scissor-like blades. Use this section to cut a 30- to 40-cm piece of wire. It may require a bit of twisting and pulling while you hold the blades clamped around the wire.

Use the same section of the pliers to strip the wire. Place one end of the wire between the blades of the long nose pliers, with several centimeters sticking out the other side. Lightly close the blades together around the wire, then gently pull the long end of the wire. If all goes well, the last few centimeters of plastic insulation should slide off. If you accidently cut off the end, just try again with the same wire, which is now just slightly shorter.

Repeat with the other end of the wire. Then repeat the entire process with several more 30- to 40-cm pieces of wire. You're going to need at least four sections of wire with the ends stripped.

Handout 6 ▸ p. 1 It's Hot, Please Close the Fan

Using a flathead screwdriver we'd hammered out of a bicycle spoke, I removed the screws from the International radio cover and tossed it aside. I removed the cassette deck, and behind it, I found the radio motor. It was half as long as my index finger and as round as an AA battery. A piece of metal stuck out from the top like a stem, attached to a small copper pulley wheel that hoisted a thin rubber belt.

I carefully extracted the motor.

—William Kamkwamba

Materials

1 pair of safety goggles for each person
1 dishpan for storing lab materials
1 organizer case for storing batteries
1 personal mini fan
2 AA batteries
1 precision screwdriver set
1 package of binder clips
4 stripped wires from the **Handout 5** activity

Procedure

1. First, let's test the personal mini fan to make sure it works. Open the battery case. Place two AA batteries in the battery holder. The plus (+) side of each battery should align with the + symbol on the case. Likewise, the minus (–) signs should also match up; the minus side of the battery holder has a small spring on it. Then move the switch to the ON position. The fan should start spinning rapidly.

2. Now take apart the entire apparatus and remove the motor. First, remove the fan itself. It should come off with a bit of gentle tugging. The rest of the case is held on by a small screw. Unscrew it with a screwdriver from the precision screwdriver set.

3. Remove the motor wire from the metal tab on the plus side of the battery holder. It is only lightly soldered onto the metal tab, and it should come off with a bit of gentle tugging. Then remove the other end from the motor. You can discard or recycle this bit of wire. Twist and bend up the metal tab on the minus side of the battery holder, where the switch used to be. The tab should stick out of the battery holder, so you can attach wires to it easily.

Handout 6 ▸ P. 2 It's Hot, Please Close the Fan

4. The tab on the plus side of the battery holder is very small. Extend it by attaching a small clip from the binder clips package.
5. Using a couple of pieces of the wire you cut and stripped earlier, figure out how to connect the fan motor so that it will run. Leave the fan attachment off, so that the entire thing doesn't flap all over the place once it's running.
6. Place two batteries in the battery holder to test it. It will probably take some trial and error. Make sure the wires are connected metal-to-metal. You may want to look at another fan that has not yet been taken apart for hints.

For any electrical device to work properly, there must be a **closed circuit**. Put another way, there must be a complete, unbroken loop of metal or other conductive material for charged particles to flow through. If there's a gap anywhere, it won't work. A circuit with one or more gaps is called an **open circuit**. Once you get the motor running, see if you can trace the path of this closed circuit.

By the way, you might be wondering if the positive and negative signs have anything to do with positive and negative charges. They do. If there's a closed circuit, then electrons, which are negatively charged, flow out of the negative side of the battery. They then flow around the circuit, and back into the positive side of the battery. Then the electrons flow through the battery and back out the other side. (Sometimes instead of electrons flowing through the battery, positively charged molecules flow the other way. But this amounts to the same overall effect.)

Does a circuit use up electrons? No. This is a common misunderstanding. A used-up battery has just as many electrons, and just as much charge, as a new, fully "charged" battery. In a circuit, the electrons just flow around and around, never leaving the circuit. The amount of electrons or other charged particles flowing around the circuit every second is called the **current**.

So what gets used up? The chemical energy in the battery gets used up. Even then, the energy doesn't stop existing. It just gets turned into other forms, such as thermal energy.

Handout 7 ▸ P. 1

Pumps and Tanks

"How do I know which head is positive or negative"? Geoffrey asked.

"If you connect the wires and you hear music, you got the right one."

"Whatever you say. Here it goes."

—William Kamkwamba and his cousin Geoffrey

Materials

1 pair of safety goggles for each person
1 motor from the **Handout 6** activity
1 AA battery
1 roll of PVC electrical tape
1 9-volt battery
1 D cell battery
4 stripped wires from the **Handout 5** activity

Procedure

1. We won't be using the battery holder any longer. You'll just need the motor from the personal mini fan.

Make a prediction to answer this question: Will the motor run with just one AA battery instead of two?

- ☐ **A.** No, one battery is not enough.
- ☐ **B.** Yes, but it will run more slowly than with two batteries.
- ☐ **C.** Yes, it will run at the same speed as with two batteries.
- ☐ **D.** Yes, and it will run even faster than with two batteries.

Now explain why you made this prediction.

Handout 7 ▸ P. 2 Pumps and Tanks

(Make a prediction, and have a reason for it, before you try the experiment! This is how science goes. It's exciting when your prediction is right, of course. But it's even more exciting when your prediction is ***wrong***. That tells you that something funny is going on. It reminds you that the universe is more interesting than you thought at first. That's how you learn science. The most boring way, of course, is to skip ahead and try to hunt for the answer. Or hope someone else has figured it out first, and get it from him or her. As the American physicist Paul Hewitt would say, that's like hoping to get stronger by watching another person do pushups.)

2. Now test your prediction. Remember, you're trying to make a complete circuit. Try a few different methods before you settle on an answer. It may help to use some bits of PVC electrical tape to hold the wires where you want them to stay. Briefly record what you tried and what happened.

3. The motor spindle rotates too quickly to count the spins. But listen carefully. When the motor is running, how can you tell if the motor is running faster or slower?

4. What will happen if you hook up the fan circuit backwards? That is, switch the minus side of the fan to the plus side of the battery holder, and the plus side of the fan to the minus side of the battery holder.

- ☐ **A.** The fan won't run.
- ☐ **B.** The fan will run backward.
- ☐ **C.** The fan will run forward.

Now explain your reasons for your prediction.

5. Test your prediction. Briefly record what you tried and what happened.

6. Make a prediction: Will the motor run with just one 9-volt battery?

- ☐ **A.** No, it's only designed for AA batteries.
- ☐ **B.** Yes, but it will run more slowly than with a single AA battery.
- ☐ **C.** Yes, it will run at the same speed as with a single AA battery.
- ☐ **D.** Yes, and it will run even faster than with a single AA battery.

Now explain your reasons for your prediction.

Handout 7 ▸ P. 3

Pumps and Tanks

7. Again, test your prediction. Unlike with the AA battery, the positive and negative terminals of the 9-volt battery are on the same end. Try to avoid letting a single wire touch both the positive and negative terminals of the battery. This will cause a **short circuit**, which will heat up and ruin your battery. Briefly record what you tried and what happened.

8. Make a prediction: Will the motor run with one D cell battery?

☐ **A.** No, it's only designed for AA batteries.

☐ **B.** Yes, but it will run more slowly than with a single AA battery.

☐ **C.** Yes, it will run at the same speed as with a single AA battery.

☐ **D.** Yes, and it will run even faster than with a single AA battery.

Now explain your reasons for your prediction.

9. Test your prediction. Briefly record what you tried and what happened.

Look at the labeling on the AAA, AA, C, and D cell batteries. Notice that they're all labeled "1.5 V." This stands for 1.5 volts. Voltage (also called electric potential) is measured in volts. Voltage is the amount of "oomph" the battery has. It tells how much energy it gives to each charged particle that passes through it per unit charge. In fact, the real name for the "oomph" of a battery is the electromotive force or emf. A battery is sort of like a water pump. The emf tells you how hard it pumps.

AAA, AA, C, and D cells all have the same emf, even though they are different sizes. The size tells you more about how much energy a battery can **store**.

So besides acting like a water pump, a battery is also like a water tank. The bigger the battery, the more it can hold in its "tank." As you use a battery, the amount of energy it has decreases, but the emf stays roughly constant. However, when the battery is close to being used up, its emf does drop by quite a bit. You've probably experienced this if you've used a cordless electric drill, electric toothbrush, or electric razor for any significant amount of time. Similarly, when you pump the last bits of water out of a tank, it may come out only in fits and spirts.

The 9-volt battery, as its name implies, has six times the emf of a 1.5-volt battery.

Handout 8 ▸ p. 1 Series and Parallel

Materials

1 pair of safety goggles for each person
2 motors from the **Handout 6** activity
6 AA batteries
1 roll of PVC electrical tape
1 9 V battery
1 D cell battery
4 stripped wires from the **Handout 5** activity
Computer access or projector to view video

Procedure

1. When you first started the fan, the two AA batteries were connected in **series**. This means that the batteries were essentially lined up, with the positive end of one connected to the negative end of the other, and with the other ends connected to either side of the motor.

Try to connect two AA batteries in series to the motor, but this time without the battery holder.

2. Make a prediction: What will happen if you run the motor with six AA batteries in series?

- ☐ **A.** The motor will run slower than with two AA batteries.
- ☐ **B.** The motor will run at the same speed as with two AA batteries.
- ☐ **C.** The motor will run faster than with two AA batteries, but slower than with a single 9-volt battery.
- ☐ **D.** The motor will run at the same speed as with a single 9-volt battery.
- ☐ **E.** The motor will run faster than with a single 9-volt battery.

Now explain your reasons for your prediction.

3. Test your prediction. Briefly record what you tried and what happened.

Handout 8 ▸ P. 2

Series and Parallel

4. Each battery "pumps" with 1.5 volts. Each battery in series makes its contribution, and pumps more energy into the moving charged particles. Of course, there is a limit to this. Once a certain number of charges is flowing by every second, the battery gets worse at pumping. You end up losing a lot of energy and just heating up the batteries. So it's very inefficient to try to make a "super battery" by connecting hundreds of batteries in series. It's also rather dangerous. Watch this video:

Fun with a few 9V batteries. (244 of them)
https://www.youtube.com/watch?v=8hwLHdBTQ7s

5. If you can put batteries in series, why not motors in series too? If you connect a single AA battery to two motors in series, how will the motors run? Make your prediction:

☐ **A.** The two motors won't run at all.
☐ **B.** They will both run, but the motor closest to the positive side of the battery will run faster.
☐ **C.** They will both run, but the motor closest to the negative side of the battery will run faster.
☐ **D.** They will both run at the same speed as each other, but slower than with one motor and one AA battery.
☐ **E.** They will both run at the same speed as with one motor and one AA battery.

Now explain your reasons for your prediction.

6. Test your prediction. Briefly record what you tried and what happened.

7. If a battery is like a pump that adds energy to the flowing charged particles in the wire, then a motor is like an "anti-pump". It removes energy from the particles by spinning the fan's spindle.

But a battery is also like a tank that stores energy. So where is the "anti-tank"? The room around you. Energy is carried away from the tank in the form of vibrating air (sound) and the vibrations of the table underneath. There's also a little friction between the parts inside the motor, which heats up the motor slightly. A small amount of energy also goes into heating up the wire and the battery.

Another way to connect multiple batteries is in **parallel**. One way to make batteries in parallel is to make them parallel in the math sense: put them next to each other and facing the same way. Once they're lined up, you can tape them together. Then tape one wire so that one of its stripped ends lies across ***all*** the negative terminals. (See image at right.)

Handout 8 ▸ P. 3

Series and Parallel

Tape a different wire the same way, but instead across ***all*** the positive terminals. (Do not use the same wire, as that will result in a short circuit.)

(See image at right.)

8. What will happen when you connect one motor to two AA batteries that are in parallel with each other?

☐ **A.** The motor will run slower than with one AA battery.

☐ **B.** The motor will run just as fast as with one AA battery.

☐ **C.** The motor will run faster than with one AA battery, but slower than with two AA batteries in series.

☐ **D.** The motor will run just as fast as with two AA batteries in series.

Now explain your reasons for your prediction.

9. Test your prediction. Briefly record what you tried and what happened.

Having two batteries in parallel is just like having two tanks of water next to each other. The combined emf gives each charged particle in the circuit the same amount of energy as it does with one battery. However, since you have two tanks, there is twice as much energy stored.

10. How fast will the motors run if you make a circuit with two motors in parallel, and one battery? What about two motors in parallel connected to two batteries in parallel? Try it! Briefly record what happened.

11. It's possible to connect two batteries so that they're in "anti-parallel." You just turn one of the batteries in parallel around, so that one battery is positive side up and the other one is negative side up.

Handout 8 ▸ P. 4 Series and Parallel

What will happen if you connect two batteries in "anti-parallel" to a single motor?

☐ **A.** It makes no difference – the motor will run in the same way it did when the batteries were in parallel.

☐ **B.** The batteries will cancel each other out, and the motor won't run.

☐ **C.** There will be a short circuit, and the batteries will start getting hot.

Now explain your reasons for your prediction.

12. Test your prediction. Briefly record what you tried and what happened.

Handout 9 ▸ P. 1

E&M Epilogue

Materials

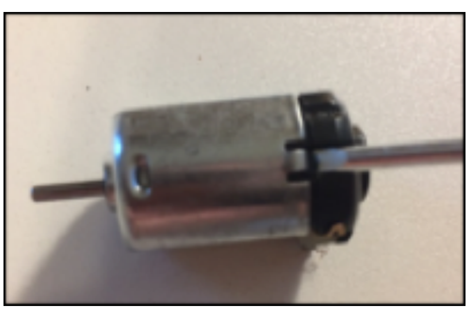
1 motor from the **Handout 6** activity
1 precision screwdriver set

Procedure

Electricity isn't magnetism, and magnetism isn't electricity. But it seems like they ***should*** be related somehow. Are they? Yes, they are. The key to it all is in this little thing.

1. First of all, test it. Is it magnetized? Is the entire thing a magnet? Briefly record what you tried and what happened.

2. OK, let's open it up. There are two little metal tabs on either side of the motor. Bend them up with a screwdriver.



Carefully pull apart the black plastic part and the metal shell. Now comes the fun. Did anyone give William Kamkwamba instructions for his windmill? Of course not. Yes, it helped a whole lot to read about some of the basic principles in *Using Energy* and other books. But in the end, he had to figure out most of it himself.

Handout 9 ▸ P. 2

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Here are some questions to guide you.

- Where's the circuit? What's the path that the electrons follow?
- Can you put it back together and make it run, but without the metal shell?
- Does the circuit pass through any magnetic part?
- What's with all the winding? (You'll see when you open it up.) How long is it?
- If there's a circuit, how does it stay closed while the thing is rotating?
- Where's the magnet? What's it doing there? Is it part of the circuit itself?

When you finally get stumped, look up "DC motor." The DC stands for **direct current**. The other major type of motor—which this one is not—is called an "AC motor". The AC stands for **alternating current**, which is the kind that typical wall outlets provide.

Have fun!

In a simple electric motor, a coil of wire on a shaft is housed inside a larger magnet. When the coil is connected to a battery and becomes magnetized, it creates a kind of fight with the larger magnet. The push and pull between the two magnetic fields causes the shaft to spin. Take, for instance, the fan that we use in hot weather. The blades spin round and round because there's a fight going on inside the fan.

—William Kamkwamba

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PO Box 65357
Albuquerque, NM 87193